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Semantic, Typicality and Odor Representation: A Cross-cultural Study

C. Chrea[1], D. Valentin[1,2], C. Sulmont-Rossé[3], D. Hoang Nguyen[4] and H. Abdi[5]

[1]Centre des Sciences du Goût, UMR 51–70, Dijon, France, [2]University of Bourgogne, Dijon, France, [3]Unité Mixte de Recherche sur les Arômes, INRA-ENESAD, Dijon, France, [4]University of Technology of Ho Chi Minh, HCM City, Vietnam and [5]The University of Texas at Dallas, Dallas, TX, USA

Correspondence to be sent to: Christelle Chrea, Centre des Sciences du Gôut, UMR 51–70, 15 rue Hugues Picardet, 21000 Dijon, France. E-mail: chrea@cesg.cnrs.fr

Abstract

This study investigated odor-category organization in three cultures by evaluating (i) the relationship between linguistic and perceptual categorization and (ii) the existence of an internal structure of odor categories. In the first experiment, three groups of 30 participants from American, French and Vietnamese cultures performed a sorting task. The first group sorted 40 odorants on the basis of odor similarity, the second group sorted 40 odor names on the basis of name similarity and the last group sorted 40 odor names on the basis of imagined odor similarity. Results showed that *odor* categorization was based on perceptual or conceptual similarity and was in part independent of *word* and *imagined* categorizations. In the second experiment, another group of 30 participants from each culture rated the typicality of the odorants for 11 odor categories. Results showed that some odorants were rated as more typical than others. Moreover, the typicality gradient predicted the odor space obtained in the odor sorting task in a consensual way among the three cultures. These results suggest that, as for other categories, odor categories are based on perceptual similarities rather than on semantic cues. Moreover odor-category structure might have a core representation which might be common to different cultures with boundaries which might be more culturally dependent.

Key words: categorization, culture, linguistic, olfaction, typicality gradient

Introduction

Perceptual categorization has generated considerable interest in cognition and perception; most of it focused on the visual modality (for a recent review, see Murphy, 2002). In this visual framework, color categories were considered an ideal domain in which 'language-cognition' research could demonstrate the effect of linguistic categories on nonverbal cognitive processes (Brown and Lenneberg, 1954; Berlin and Kay, 1969; Rosch, 1973). The main results of this research were that (i) colors tend to be universally clustered and a few basic terms express universal features of color perception; and (ii) colors are not all equivalent in a category: some colors are more representative of the color category, and are said to be more typical of this category than other colors are. Here we want to know whether the approach used in the study of color categorization could be extended to odor categorization. Odor classification has been investigated since the nineteenth century by researchers from various fields such as botanic, biology, chemistry and perfumery. But in contrast to the visual modality, no universal primary sensation has yet emerged from any of these studies (for a recent review, see Chastrette, 2002). But a linguistic study carried out by Dupire (1987) showed that the N'Dut (an African ethnic group from Senegal) use a few basic terms in order to classify the overall odor environment in only five categories (i.e. scented, milk-fishy, rotten, urine-like, acidic). In another study carried out in two cultures (German and Japanese) without any abstract terms to describe odors, Schleidt *et al.* (1988) found that odor memories can similarly be classified into a few categories across these two cultures (i.e. civilization, food and drink, nature, man, remainder). These categories are somewhat similar to the categories previously found by Dupire (1987) in that fecal odors, human odors and material in decomposition are classified as unpleasant, whereas odors from vegetation are classified as pleasant. These two studies suggest that odors might be structured in categories rather than perceived as 'unitary perceptual events', as proposed by Engen and Ross (1973). However, these two studies involve the classification of 'odorant objects' and thus are concerned with linguistic categorization of odors, rather than odor categorization *per se.*

In fact, only a few studies have been carried out to investigate the existence and consistency of odor categories *per se.* Ueno (1993) found that Japanese and Sherpa participants agreed on how to sort 20 artificial Japanese aromas on the basis of their perceptual similarity, with the exception that the Japanese classification revealed a 'fishy' category that did not emerge in the Sherpa classification. The authors hypothesized that this difference might be due to the fact that fish odors are rarely encountered by Sherpa people. (Sherpa is an ethnic group of Nepal). More recently in the same vein, Chrea *et al.* (2004) asked participants of American, French and Vietnamese cultures to sort freely 40 everyday odorants. Multidimensional scaling analyses of these data showed that four common clusters (i.e. sweet, floral, bad and nature) emerged for the three groups of participants. In addition, Chrea *et al.* found differences at a finer level, which may have been due to differences in food habits. For instance, wintergreen—which is used as candy or soda flavor in the USA—was put in the 'sweet' cluster by most of the American participants while it was put in the 'medicine' cluster by French participants and in the 'floral' cluster by Vietnamese participants. Those results are in agreement with Ueno's results and suggest that odor perceptual categorization depends in part on familiarity or frequency of exposure with specific odors.

Both Ueno (1993) and Chrea *et al.* (2004) support the hypothesis derived from linguistic studies that odors might be organized in consensual categories across different cultures. These studies, however, did not explore—contrary to what was done for colors—the similarity between linguistic and perceptual categories, nor did they explore the organization of the perceptual categories themselves. The aim of the present study is to address this issue by expanding Chrea *et al.*'s work.

In the first experiment, we evaluated the relationship between linguistic categorization as reported by Dupire (1987) and Schleidt *et al.* (1988), and odor categorization *per se* as reported by Ueno (1993) and Chrea *et al.* (2004). To achieve this goal, we compared the perceptual categorization of odorant stimuli (*odor* condition reported in Chrea *et al.*) with two linguistic categorizations of odor names. In the first linguistic categorization, we asked participants from American, French and Vietnamese cultures to sort the names of the odorants from the Chrea *et al.* study on the basis of their similarity without telling the participants that words referred to odor names (*word* condition). In the second linguistic categorization, we asked another group of participants—from the same three cultures—to imagine the odors from the odor names and to sort them on the basis of the similarity of their imagined odors (*imagined* condition). In the second experiment, we were interested in evaluating whether we can find an odor-category internal structure similar to the one described by Rosch (1973) for color categories. Rosch showed that color categories are structured along a typicality gradient in that some exemplars are better and more representative than others, even in cultures such as the Dani (an ethnic group of New Guinea), where language lacks basic terms to describe colors. Previous work by Dubois (2000) suggests that odor categories might be structured according to internal properties such as typicality. To examine further the existence of such a typicality gradient in odor categories, we first extracted eleven category names from the odor sorting data collected in Chrea *et al.* study. We then asked another group of participants from each culture to rate the typicality of the odorants for these eleven odor categories on a 7-point scale. We finally evaluated whether we can predict the odor space resulting from the sorting task by the typicality ratings.

Experiment 1: Relationship between linguistic and odor categorization

Materials and methods

Participants

Three groups of 30 participants from each culture were recruited from the University of Texas at Dallas (USA), the University of Bourgogne at Dijon (France) and the Polytechnic Institute of Danang (Vietnam). Groups were comparable in gender and age distribution, both across tasks and across cultures. The participants were born and raised in the country of the experiment. None of the participants were informed of the real aim of the experiment. In the *word* condition, to ensure that participants performed the task on word rather than odor similarity, participants were told that the experiment aimed at studying language representation. In the two other conditions, the participants were told that the experiment aimed to investigate odor perception.

Stimuli

Odorants. We used 40 odorants selected from an initial set of 56 odorant samples provided by Sentosphère (Paris, France). To select these odorants, we used familiarity rating scores collected in a previous study (Ly Mai, 2001). The odorants were selected so that 17 of them were equally familiar in all three cultures, six were rated as more familiar in France, six were rated as more familiar in the USA and 11 were rated as more familiar in Vietnam. The evaluation of the rating was obtained from a two-way analysis of variance with culture as the between-participant independent variable and odor as the within-participant independent variable. The odorants were microencapsulated and presented in 2 cm high punched plastic flasks randomly coded by a two-digit code number. Participants were asked to shake the flask before opening it and to bring it up close until the opened flask was about 1 centimeter under their nose. Participants were instructed to smell the odorants by breathing normally, without sniffing. They could manipulate the stimuli freely with no time limitation. In order to reduce olfactory adaptation, participants were asked to wait for 15s between two odorants. Although a longer interval delay is generally recommended between two trials to reduce the cross-adaptation phenomenon

(Köster, 1971), we had to deal with the natural speed at which the participants wanted to perform the task. We observed, however, that participants spontaneously took more time between two samples when they felt it necessary. If a participant perceived no odor when smelling an odorant, he or she did not perform the task for that odorant.

Word and imagined conditions. For each culture, odor labels were obtained from a multiple-choice identification task performed by the odor sorting group. The aim of this task was to select the most consensual label attributed to each odorant in order to obtain labels which made sense for a given culture. When the participants had completed the sorting task (see below), they were asked to re-smell each odorant and to find the name of its odor among a list of 90 labels: the 40 labels given by Sentosphère to the odorants and 50 additional labels frequently given in a previous free identification task of the 40 odorants (Ly Mai, 2001). For each odorant, the label associated with the highest frequency of citation was selected. When this frequency was ≤10%, the label provided by Sentosphère was selected. This occurred approximately equally in the three cultures (6, 10, and 11 respectively for France, USA and Vietnam) and was expected because in each culture, some odorants were unfamiliar. The 40 labels selected in each culture are presented in Table 1. Each label was written down on a card in capital letters in the native language of each culture.

Procedure

Participants sat at a table to perform the task. Stimuli (odors or printed label cards) were presented to the participants arranged on the table in random order. Participants were asked to smell/read the stimuli and to sort them on the basis of their similarity. In the *imagined* condition, participants were instructed to imagine the odors of the 40 odor labels and sort the words on the basis of the imagined odor similarity. In all conditions, participants could sort the stimuli into as many groups as they wished, and each group could contain as many stimuli as the participants wished. After completion of the sorting task, participants were asked to provide a few words to describe each of the groups they had formed.

Experimental conditions

In the *odor* condition, the task was conducted in a well-ventilated room under red light in order to mask evident differences in the color of the plastic flasks. In the *word* and the *imagined* conditions, the task was conducted in a standard classroom in daylight.

Results

We started by deriving pairwise similarity estimates by counting the number of times two items were sorted into the same group over all the participants in each culture and each sorting condition. These co-occurrence matrices were submitted to a multidimensional scaling analysis (MDS) using a non-parametric alternating least-squares scaling algorithm (ALSCAL; see e.g. Borg and Groenen, 1997). For all three cultures and all three sorting conditions, three-dimensions were selected as the most appropriate MDS solution (the stress values of the MDS solutions were respectively 0.16 in the *odor* condition, 0.13 in the *word* condition and 0.17 in the *imagined* condition for France; 0.16, 0.14 and 0.17 for the USA; and 0.18, 0.16 and 0.18 for Vietnam). This analysis was completed by a hierarchical cluster analysis (HCA) performed on the results of the MDS analysis. Here we present only the results of the HCAs.

To select the number of clusters yielded by the HCAs, we examined the dendrograms for large changes in level. Specifically we used an approach similar to the scree test (the 'elbow-test') used in principal component analysis. For each level of the cluster analysis, we computed (using SAS PROC CLUSTER) the root-mean-square standard deviation corresponding to this level. We selected the number of clusters corresponding to the largest difference between two consecutive levels (Milligan and Cooper, 1985). We found, for France, five clusters in all three sorting conditions. For the USA we found four clusters in the *odor* and *imagined* conditions and six in the *word* condition. Finally, for Vietnam we found four clusters in the *odor* condition, and five clusters in the *word* and *imagined* conditions. Figure 1 shows a simplified representation of the clusters yielded by the HCAs in the three conditions for the three cultures. In this figure, each cluster is labeled by a few generic terms, which represent the most frequent descriptors given by the participants.

Global comparison of cluster memberships across the three conditions

We first looked at the simplified dendrograms and focused on the cluster memberships to compare the three sorting conditions within a culture. Three similar findings in all three cultures emerged from Figure 1. These findings are described below.

Similarity in the macrostructure and differences in the microstructure. In all three sorting conditions, three common clusters emerge. A first cluster includes mostly fruit items, a second one mostly flower items, and a last one mostly animal and musty items. Besides those three common clusters, some items are grouped differently in the three sorting conditions (e.g. clove, ginger and nutmeg for France, cat pee and civet for the USA, mushroom and moldy for Vietnam).

Specific clusters common to word and imagined conditions. A 'food' or 'fatty' cluster—including mainly nuts, milk and butter items—appears in the *word* and *imagined* conditions, but not in the *odor* condition. On the same line, a 'cleaners' cluster—including mainly chemical and cosmetic products—appears for the French and American groups in the *word* and *imagined* conditions, while cleaning products are sorted with the flower items in the *odor* condition for both of these cultures.

Table 1 Odorants provided by Sentosphère and labels for the *word* and *imagined* sorting task conditions

Odor	Abbreviation	French label	American label	Vietnamese label
Amber	**AMB**	**amber**	baby powder	baby powder
Anise	**ANI**	anise	licorice	anise
Apricot	**APR**	**apricot**	**apricot**	**apricot**
Blackcurrant	**BLA**	blackcurrant	raspberry	lemon
Butter	**BUT**	cheese	butter	butter
Cat pee	**CAT**	cat pee	cat pee	**cat pee**
Cinnamon	**CIN**	cinnamon	cinnamon	cinnamon
Civet	**CIV**	feces	feces	feces
Clove	**CLO**	clove	clove	tooth medicine
Cookies	**COO**	caramel	icing	cookies
Detergent	**DET**	detergent	detergent	detergent
Eucalyptus	**EUC**	eucalyptus	nose medicine	eucalyptus
Ginger	**GIN**	ginger	**ginger**	ginger
Hazelnut	**HAZ**	hazelnut	hazelnut	**hazelnut**
Honey	**HON**	honey	**honey**	honey
Jasmine	**JAS**	jasmine	honeysuckle	jasmine
Lavender	**LAV**	lavender	**lavender**	lemon grass
Leather	**LEA**	leather	leather	**leather**
Mango	**MAN**	**mango**	**mango**	**mango**
Melon	**MEL**	melon	watermelon	jack-fruit
Milk	**MIL**	butter	pop corn	milk
Mothball	**MOT**	moth ball	bathroom cleaner	insecticide
Moldy	**MOL**	moldy	earth	moldy
Mushroom	**MUSH**	mushroom	**mushroom**	mushroom
Musk	**MUS**	**musk**	**musk**	**musk**
Nutmeg	**NUT**	nutmeg	**nutmeg**	plastic
Orange blossom	**ORA**	orange blossom	**orange blossom**	flower of grapefruit
Peanut	**PEA**	peanut	peanut	peanut
Pine	**PINE**	**pine**	pine	pine
Pineapple	**PIN**	pineapple	pineapple	pineapple
Rose	**ROS**	rose	rose	**rose**
Soap	**SOA**	soap	soap	soap
Strawberry	**STR**	strawberry	strawberry	strawberry
Tea	**TEA**	**tea**	beef jerky	**tea**
Truffle	**TRU**	truffle	cheese	fish sauce
Vanilla	**VAN**	vanilla	vanilla	**vanilla**
Violet	**VIO**	violet	**violet**	**violet**
Walnut	**WAL**	walnut	pecan	traditional medicine
Wintergreen	**WIN**	nose medicine	wintergreen	mint
Woody	**WOO**	earth	cedar	**woody**

Labels in bold are those provided by Sentosphère when the percentage identification was <10%.

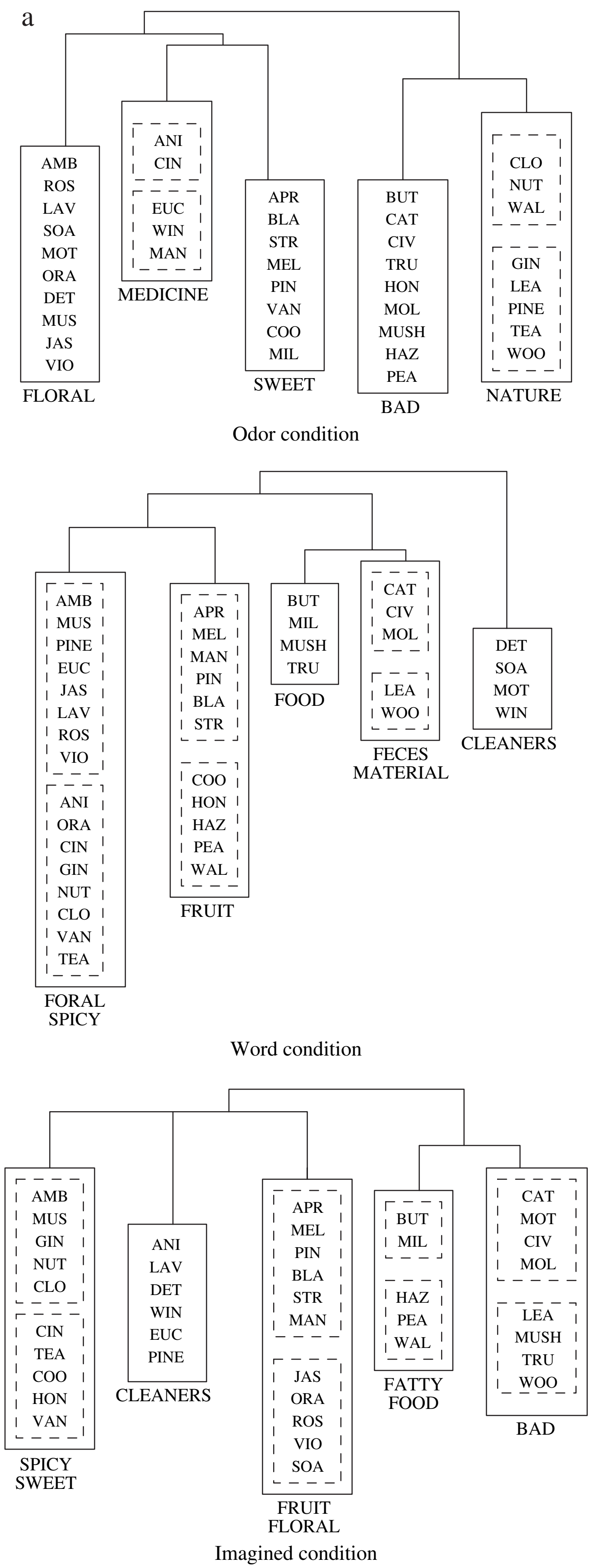

Figure 1 Composition of the clusters for all three sorting conditions in **(a)** France, **(b)** USA and **(c)** Vietnam, respectively. Clusters were selected on the basis of the first large change in levels. When a second large change occurred in the dendrogram, sub-clusters are marked with a dashed line.

A stronger hierarchy in the word space. A higher heterogeneity in cluster size in the *word* condition compared to the two other sorting conditions appears. Some clusters include only two or three items, whereas others include up to 12–20 items and show some obvious sub-divisions. For instance, as seen in Figure 1, the French 'floral–spicy' cluster is subdivided in 'floral' and 'spicy' sub-clusters at a finer level of the dendrogram. The Vietnamese 'vegetation–fruity' cluster is subdivided in 'floral' and 'fruity' sub-clusters.

These first observations indicate that odors are not categorized in the same way as the names associated with the odors. In addition, imagined categorization seems to be closer to the word categorization than to odor categorization.

Distances between the cluster partitions among the three sorting conditions

To examine more precisely the level of similarity between the three sorting conditions and the three cultures, we computed distances between the cluster partitions yielded by the HCAs. The distance we used is called the symmetric difference distance (sometimes called the 'Hamming distance'). The symmetric difference distance is a distance defined between sets of objects; it corresponds to the number of elements which belong to only one set (see e.g. Carré, 1979, p. 7). In the present work, the distance between two clusters is the number of odors which are present in one cluster and not in the other. Smaller values of the distance indicate that two clusters share a large number of items, while a large value indicates that two clusters include different items.

Table 2 reports these distances. A first point to note is that, in France and in the USA, the cluster partition in the *odor* condition is equally distant from the partitions in the *word* and the *imagined* conditions. In contrast, for Vietnam, the cluster partition in the *odor* condition is much closer to the partition in the *imagined* condition than to the partition in the *word* condition. A second point is that distances are smaller between cluster partitions among the three cultural groups within the *odor* condition than between cluster partitions in the *word* and *odor* conditions within a culture. This result suggests that the consensus between the three cultural groups in categorizing odors is quite robust because this consensus is stronger than the consensus within a culture in categorizing odors and odor names.

Prediction of perceptual categorization by linguistic categorization

To evaluate whether we can predict the space obtained in one sorting condition from the space obtained in another condition, we performed a series of linear regressions on the

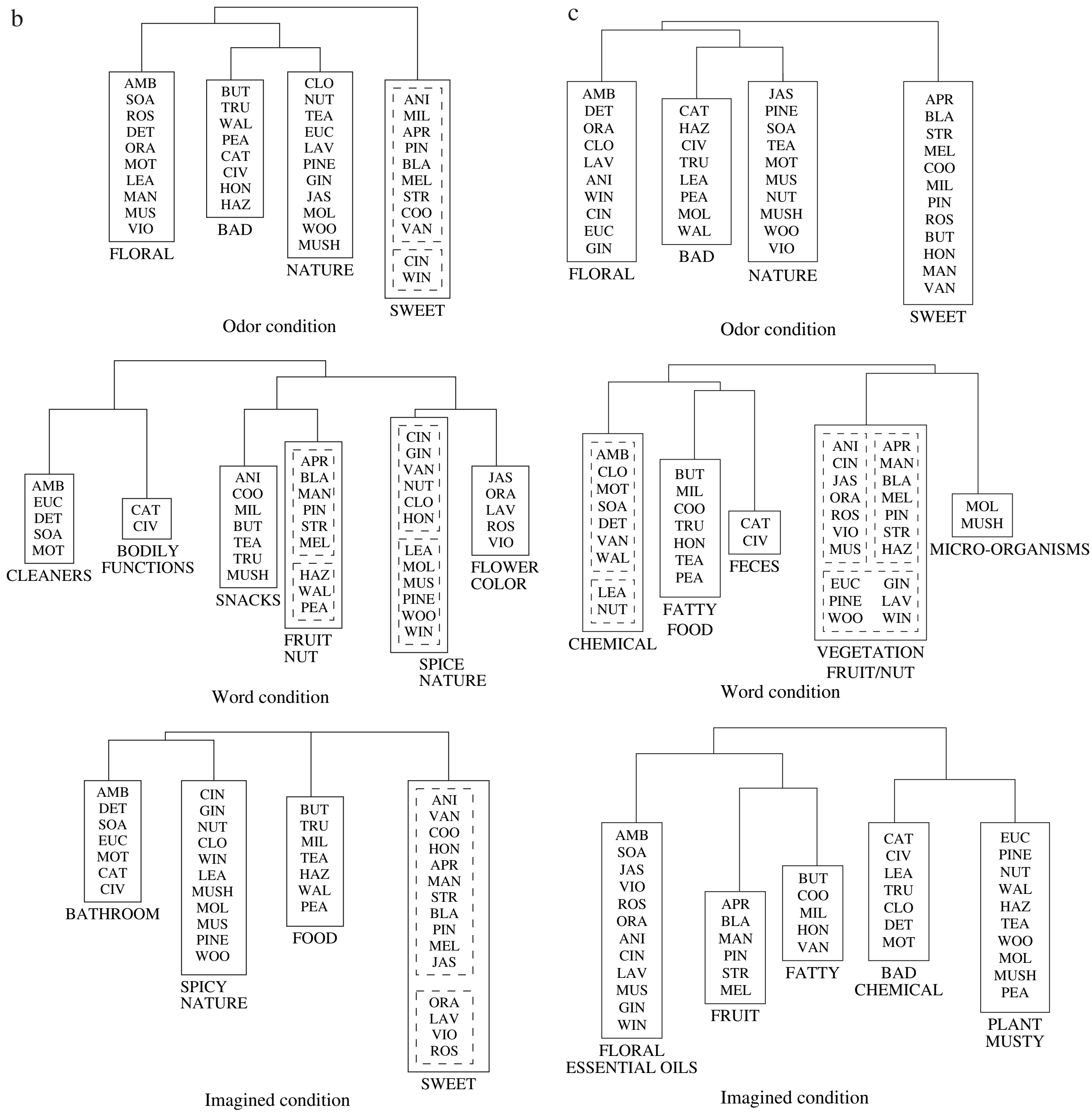

Figure 1 Continued.

Euclidian distance matrices resulting from the MDS analyses in the three sorting conditions. Table 3 reports the coefficients of determination and their significance. The regression analyses are all highly significant for all three cultures. But it is worth noting that this high significance may be due to the large number of degrees of freedom of the regression analysis. The determination coefficients show that the *odor* space is better predicted by the *imagined* space than by the *word* space in all three cultures, but the difference of variance explained by the two predictors is small. Besides, the *word* space predicts the *imagined* space much better than it predicts the *odor* space. These findings suggest that asking participants to imagine

Table 2 Values of the symmetric difference distance (1) between the cluster partitions in the three experimental conditions within a culture and (2) between the cluster partitions in the three cultures within the *odor* condition

(1) Culture	Odor versus word	Odor versus imagined	Word versus imagined
France	193	208	199
The USA	238	235	267
Vietnam	228	191	165
(2) Odor condition	France versus the USA	France versus Vietnam	The USA versus Vietnam
	136	183	211

Table 3 Determination coefficients (R^2) and their statistical significance between the three experimental conditions for all three cultures (n = 760)

	France	USA	Vietnam
Odor versus word	0.12, $P < 0.0001$	0.14, $P < 0.0001$	0.06, $P < 0.0001$
Odor versus imagined	0.19, $P < 0.0001$	0.17, $P < 0.0001$	0.23, $P < 0.0001$
Imagined versus word	0.33, $P < 0.0001$	0.53, $P < 0.0001$	0.22, $P < 0.0001$

odors tends to increase just a little the prediction of a perceptual categorization by a linguistic categorization of odor names. Finally, there is a better prediction of a linguistic categorization by another linguistic categorization than a perceptual categorization by one of the two linguistic categorizations.

Discussion

The results of Experiment 1 suggest that perceptual categorization is in part independent of linguistic categorization. Whereas words tend to be classified on the basis of biological taxonomy, odors tend to be categorized on the basis of their perceptual similarity. However, we cannot completely rule out the hypothesis that odor categories may be affected by semantic associations. Indeed, fruit and flower odorants, identified as fruity or floral by most of the participants in the three cultural groups, were grouped in the same way in the *word* and *imagined* conditions. We might suppose that identification of the odors during the sorting task helped participants to find some lexical criteria to form their groups. This result is in concordance with the suggestion of Chastrette *et al*. (1988) that for odors such as 'fruity' or 'floral', odor classification is driven more by the semantic classification of the odorant sources than by the perceptual similarities. Nevertheless, our results showed a contradictory example with nut odors, sorted in the 'bad' cluster by almost all participants in the three cultural groups in the *odor* condition. Indeed, the results showed that even participants successful in identifying nut odors in the multiple-choice identification task sorted them in the 'bad' cluster. In contrast, nut items were mostly sorted with fruit items in the *word* condition.

Finally, we found that the *odor* categorization was equally distant from the *word* and the *imagined* categorization for France and the USA, while for Vietnam, *odor* categorization was closer to *imagined* categorization than to *word* categorization. The results for the Vietnamese group are consistent with a study of Sugiyama *et al.* (2003), who asked Japanese participants to perform a pair similarity judgement task in either an odor, linguistic, or imaginary condition. Using procrustean distances to compare the three MDS solutions, these authors also found a greater similarity between perceptual and imaginary spaces than between perceptual and linguistic spaces. A plausible explanation for these results may be that in both studies odorants were not very familiar to participants and thus difficult to identify. The distance between odor categorization and odor names categorization might therefore be due to the inadequacy between the odorant source names and the participants' mental representations of the odors. However, in contrast with our study, the odorants used in the Sugiyama *et al.* study were manufactured in the country of the participants. Also, because no indication was reported on the participants' ability to identify the odors, it is difficult to evaluate the actual familiarity of Sugiyama *et al.*'s participants with the odors.

Experiment 2: Internal structure of odor categories

In the previous experiment we showed that the perceptual organization of odors did not match the linguistic organization of the names associated with odors. In this experiment we explore further the mechanisms underlying perceptual organization by investigating the existence of an internal structure in odor categories such as a typicality gradient. Moreover we want to evaluate whether this perceptual organization is culture dependent or consensual among the three cultural groups.

Materials and methods

Participants

A group of 30 participants was recruited from the University of Texas at Dallas (USA), the University of Bourgogne at Dijon (France) and the Polytechnic Institute of Danang (Vietnam). Groups were comparable in gender and age distribution across the cultures. The participants were born and raised in the country of the experiment. All were naive to the purpose of the experiment and were not familiar with olfactory testing.

Stimuli

The stimuli were the same as in the *odor* condition of Experiment 1. Odorants were coded by a random three-digit code number.

Procedure

The participants were presented with the 40 odors in a randomized order. After smelling an odorant, participants were asked to rate the typicality of its odor for 11 categories, namely fruit, flower, candy, cleaner, animal, musty, bakery, cosmetic product, spice, medicine and nature. These categories were selected on the basis of the descriptors provided by the participants in the *odor* sorting task. The participants gave their answers on 7-point scales labeled at each end of the scale (e.g. 'How typical is this odor of a *fruit* odor? Not typical at all/very typical'). To ensure that the participants understood the notion of typicality, they were given the following instruction before beginning the task: 'Imagine that you are explaining to an extraterrestrial what a ''fruit'' smell is. Would you choose this odor to illustrate this concept of a ''fruit'' smell?'

The presentation order of category names was counterbalanced across participants, but, to facilitate the participant's task, the order was the same for all odors for an individual participant. The participants answered on an Apple McIntosh computer running the PsyScope data acquisition software (Cohen *et al.*, 1993). For each odorant, category names appeared on different screens, this was done to obtain answers that were as independent as possible. The experimental conditions were identical to the ones in the *odor* condition in Experiment 1.

Results

We first averaged the 11 typicality ratings of each odorant across the participants in all three cultures. We then examined the agreement between typicality ratings and cluster memberships. Finally, to evaluate further whether clusters yielded by the HCAs were organized around a typicality gradient, we performed a series of discriminant analyses. This analysis used the 11 typicality ratings to predict the classification of the 40 odors into the clusters obtained in the *odor* condition of Experiment 1.

Agreement between typicality judgement and cluster membership

Globally there is a consensus across the three groups of participants to evaluate some odorants as more typical of a given category than others (cf. Appendix 1). For instance, in all three cultures, clove and garlic are rated as more typical than anise or vanilla for the spice category. Likewise, honeysuckle and amber are rated as more typical than musk or lavender for the cosmetic product category. Moreover, for some items, there is a strong agreement between the cultural consensus in the membership of the sorting task and the cultural consensus in the typicality ratings. For instance, melon, pineapple and strawberry—which are rated as very typical of fruit and candy categories by the three groups of participants—are also common to all three cultures in the 'sweet' cluster. In the same way, civet, cat pee and moldy—which are rated as very typical of animal and musty categories by the three groups of participants—are common to all three cultures in the 'bad' cluster. Besides this agreement, some cultural differences are also obvious for some odorants. For instance, wintergreen was put in the 'sweet' cluster only in the USA, and was rated as more typical of the candy category in the USA (mean score 4.16) than in France (1.50) or in Vietnam (2.70). Along the same lines, mango was put in the 'sweet' cluster only in Vietnam, and was rated as more typical of the fruit category in Vietnam (4.20) than in France (2.90) or in the USA (2.74).

Prediction of the cluster membership by the typicality gradient

The discriminant analysis produces significant results for all three cultures [$F(44,77) = 5.63$, $P < 0.0001$ for France, $F(33,77) = 9.10$, $P < 0.0001$ for the USA, $F(33,77) = 3.28$, $P < 0.0001$ for Vietnam]. Three significant discriminant functions for France and the USA and two discriminant functions for Vietnam maximize the discrimination of the 40 odorants. Together, these linear discriminant functions account for 97% of the variance for France, 99% for the USA and 91% for Vietnam. Thus, in all three cultures typicality ratings predict the classification of the odors in the clusters resulting from the odor sorting task.

Table 4 shows the matrix of correlations between typicality ratings and significant discriminant functions. We can see that only a few common typicality ratings contribute strongly to the formation of odor clusters in all three cultures. Indeed, the candy typicality rating has the strongest loading on the first function for all three cultures. This means that the first function discriminates the clusters mainly according to a candy typicality gradient in all three cultures. For the second function, musty and animal typicality ratings have a strong loading for the USA and Vietnam, while cleaner, candy, and fruit typicality have the strongest loading for France. Finally, cosmetic typicality has a strong loading on the third function for both France and the USA. But, as shown in Figure 2, the discrimination of the clusters is not identical among the three cultures. For instance, the first dimension opposes bad and nature clusters to sweet, medicine and floral clusters in France, whereas this first dimension opposes sweet to floral and nature clusters in both the USA and Vietnam.

Discussion

We found that some odorants were rated as more typical of a given category than others. These results suggest that odors

Table 4 Matrix of correlations between the eleven typicality ratings as predictors and the discriminant functions

Predictors	France			USA			Vietnam	
	Function 1	Function 2	Function 3	Function 1	Function 2	Function 3	Function 1	Function 2
Spice	−0.10	−0.17	−0.42	0.06	−0.06	0.37	−0.10	0.38
Candy	0.51	0.44	−0.23	0.57	−0.59	0.14	0.77	0.36
Musty	−0.28	0.00	−0.06	−0.16	0.75	0.07	−0.36	−0.62
Cleaner	0.16	−0.47	0.50	−0.32	−0.20	−0.18	−0.25	−0.13
Bakery	0.16	0.32	−0.03	0.24	0.09	0.05	0.64	0.11
Cosmetic	0.42	−0.09	0.42	−0.18	−0.32	−0.78	0.18	0.43
Nature	−0.11	0.00	0.01	−0.16	0.33	0.28	0.05	0.49
Animal	−0.39	0.13	0.10	−0.01	0.58	0.07	−0.33	−0.53
Flower	0.22	−0.16	0.38	−0.03	−0.30	−0.20	0.37	0.64
Medicine	0.16	−0.18	−0.35	−0.12	−0.14	0.32	−0.27	0.27
Fruit	0.42	0.45	−0.08	0.22	−0.31	−0.07	0.64	0.38

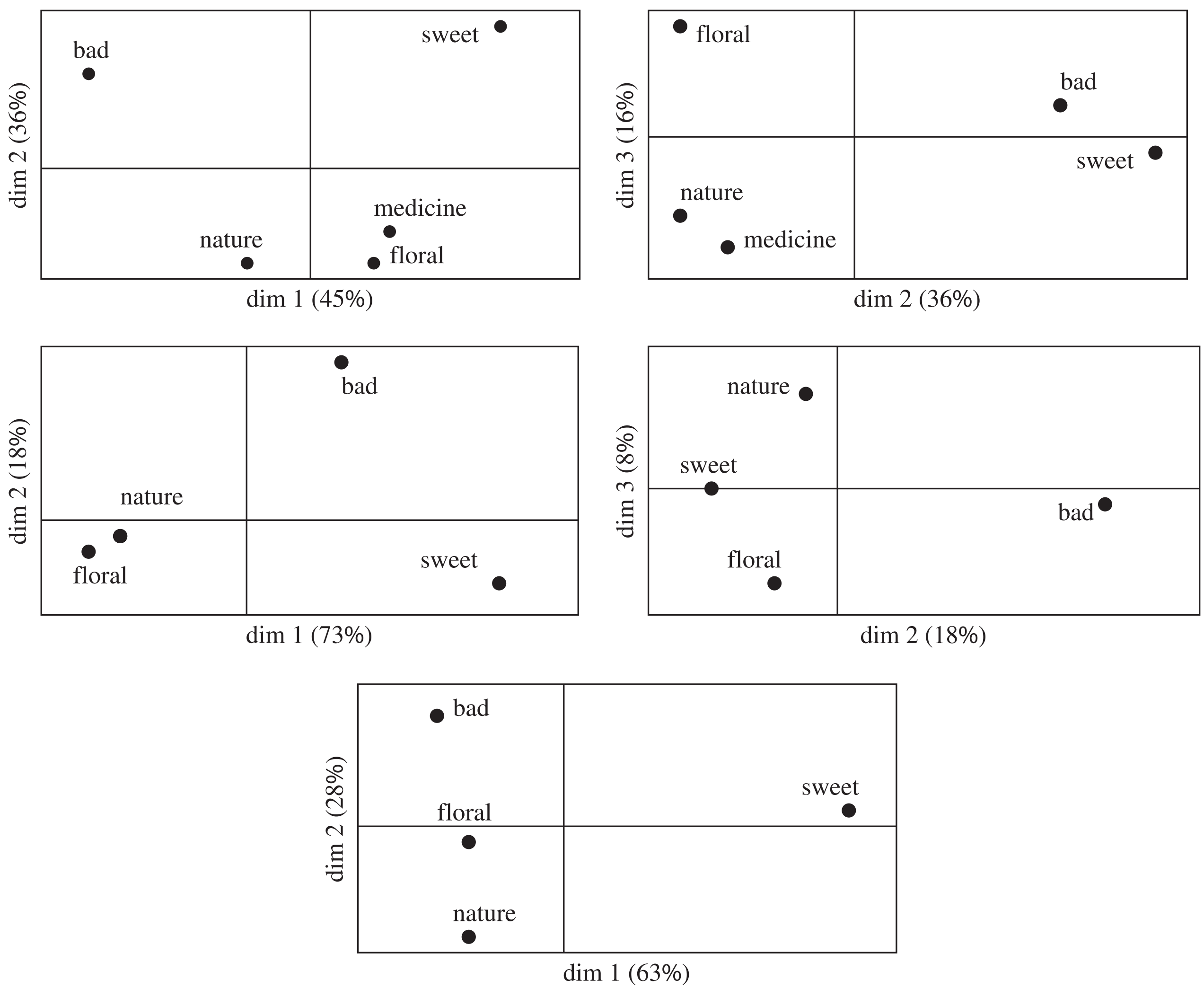

Figure 2 Plots of odor clusters on the discriminant functions derived from 11 typicality ratings for **(a)** France, **(b)** USA and **(c)** Vietnam, respectively.

within a category are not all equivalent. Moreover, the results of the discriminant analysis showed that odorants were discriminated globally in all three cultures by four typicality ratings (candy, animal, musty and cosmetic). The strong contribution of these typicality ratings was consistent with the nature of the four common clusters emerging from the odor sorting task. It shows that the consensus to categorize odors is closely linked to the consensus to judge the typicality of odors. However, our results revealed that some variability in typicality ratings contributed also to cultural differences in cluster discrimination. This variability may be due to cultural differences in consumption for food and cosmetic products and also to cultural differences in familiarity with some specific odors.

The question remains, why are some odors perceived as more typical than others? Holley (2001) suggests that some odors may be more typical because they have acquired a particular perceptual saliency. Current theories about olfactory receptor physiology and the existence of specific anosmias suggest that, while most odor receptors tend to respond to a wide range of odors, some might have more narrow sensitivity spectrum (Holley, 1996). Odors to which these high selectivity receptors are preferentially tuned might be more salient and therefore might be judged as more typical of a category. Another possibility is that typicality is linked to the familiarity with the odors within the culture: more familiar odors may be judged as more typical than odors that are less familiar. However, we found an example that is not consistent with this hypothesis: melon—rarely encountered in Vietnam and not included among the most common fruits either in the USA or in France—was nevertheless judged as the most typical fruit odor by all three groups of participants. Although we cannot be sure that there is not another fruit in Vietnam that has a melon-like odor (melon was identified as jackfruit by 19% of Vietnamese participants in the multiple-choice identification task), this example suggests that familiarity is not the only determinant of typicality.

General discussion

Our first objective was to evaluate the relationship between odor categorization *per se* and the linguistic categorization of names associated with odors. Some authors have argued that linguistic devices are cues to access odor representations (Dubois, 2003). Contrary to this hypothesis, our results showed that odor categorization does not fit the linguistic categorization of odor names because odors and odor names were categorized differently. Only for some odorants, such as fruit and flower odorants, was there a similarity of clustering observed between *odor* and *word* conditions. In addition, when asked to imagine odors from the odor names, participants could not free themselves from semantic cues and categorized imagined odors mostly on the basis of the odor names. This suggests that participants had some difficulty in imagining odors and thus might have based their categorization on semantic cues rather than perceptual cues.

The results are consistent with previous work suggesting that 'people do [perceptually] categorize odors, but not with semantically cohesive general nouns' (Engen, 1987, p. 500). This may be due to the fact that odors are difficult to name and people's verbal responses to them tend to be idiosyncratic (Herz and Engen, 1996). Another possibility is that odor categorization is more conceptual than linguistic, and that odors are categorized according to the function attributed to the odorant objects. Our results revealed, for instance, that wintergreen, mango and cinnamon, which are used in different contexts in the three cultures, were grouped differently by the three cultural groups (for more details, see Chrea *et al.*, 2004). This is in agreement with what Dubois (1997) calls 'pragmatic factors of human activities' (e.g. hunting, cooking, domestic life, corporal odors) which may be the main factors that drive the categorization and naming, rather than common perceptual constraints.

The second aim of this study was to investigate whether an internal structure might drive odor category formation. Our results revealed that the typicality gradient seems to predict the structure of the odor space. Moreover, our results suggest that the core representation of an odor category might be universal, whereas the periphery of the category—including the atypical exemplars of the category—might be more culturally dependent. This interpretation, which still needs to be confirmed with other population samples, would be in agreement with the claim that, as suggested by Rosch (1973) for other natural categories, odor categories are universally organized around some prototypes but have no rigid boundaries. Previous work by Labov (1973) for object categories and Lawless *et al.* (1991) for odor categories showed that category boundaries are often fuzzy and can vary depending upon the context. Our results show that, in addition to contextual factors, shifts in category boundaries might also be explained by cultural factors, such as familiarity with some specific odors, or by the function attributed to the odors.

Conclusion

Our results provide an insight into the way odor categories are organized. According to the universal–prototypical point of view, odors tend to be encoded in much the same way as colors. However, 'while the structure of colors in memory comes to resemble the structure of color names in a given language' (Heider and Olivier, 1972, p. 338), odors are rather categorized on the basis of perceptual and odor-context similarity. Another difference between odors and colors is that it is easy to conjure up a mental image of a color just after hearing a color name, whereas such an association between an odor name and its mental image seems more difficult to access. This pattern of results suggests that the cognitive processing of odors is not completely similar to the processing of colors and confirms the claim that odor encoding leads to specific cognitive mechanisms.

Appendix 1 Typicality mean scores for the 11 odor categories and the three cultures (FR =.France; US The USA; VN Vietnam)

Odors	animal			bakery			candy			cleaner			cosmetic		
	FR	US	VN	FR	US	VN	FR	US	VN	FR	US	VN	FR	US	VN
amber	1.17	1.05	1.87	1.83	1.16	2.53	2.27	1.58	2.73	2.63	2.37	2.07	4.03	4.53	3.57
anise	1.07	1.00	1.63	2.20	2.16	2.67	6.03	6.05	3.53	1.77	1.47	2.03	1.37	1.21	2.73
apricot	1.07	1.26	1.63	2.30	1.95	3.40	5.23	3.84	5.03	2.73	2.05	1.53	3.30	2.47	3.23
blackcurrant	1.03	1.37	1.43	2.20	1.74	3.27	6.63	5.42	4.43	1.90	1.84	1.83	2.00	1.58	2.53
butter	2.97	2.26	2.03	1.37	3.16	3.43	1.30	1.32	3.40	2.10	1.53	2.13	1.43	1.42	3.07
cat pee	3.50	5.21	2.07	1.00	1.05	1.73	1.03	1.37	1.70	2.03	2.21	2.23	1.37	1.68	2.23
cinnamon	1.33	1.11	1.57	2.67	4.26	2.87	2.47	5.11	3.20	1.97	1.32	1.77	1.80	2.00	3.07
civet	4.80	4.79	3.97	1.00	1.05	1.57	1.07	1.26	1.40	1.67	1.58	3.03	1.10	1.00	1.77
clove	1.23	1.37	2.27	1.43	2.89	1.83	1.37	2.63	1.80	2.00	1.37	2.37	1.40	1.47	2.43
cookies	1.03	1.00	1.33	4.37	4.33	5.40	5.27	4.33	4.83	1.53	1.56	1.77	2.77	3.00	3.43
detergent	1.37	1.37	2.37	1.13	1.32	1.73	1.20	1.16	1.90	5.47	4.58	3.10	2.03	3.42	3.33
eucalyptus	1.03	1.32	1.43	1.00	1.05	1.73	4.10	1.63	2.33	3.40	4.37	1.80	1.33	1.42	2.93
ginger	1.27	1.53	1.73	1.47	2.05	2.97	2.43	1.63	3.77	3.30	3.37	2.00	1.87	1.53	2.93
hazelnut	1.77	2.22	2.70	4.23	2.94	2.63	3.27	3.22	2.33	1.13	1.33	1.90	1.10	1.61	2.30
honey	2.03	2.33	2.67	2.10	2.28	2.27	2.80	2.17	2.80	2.13	2.22	2.40	1.27	1.06	2.27
jasmine	1.70	1.63	2.57	1.13	1.47	2.10	1.23	2.05	2.33	3.30	2.74	2.93	2.97	3.05	2.77
lavender	1.07	1.05	1.80	1.00	1.16	1.83	1.27	1.47	2.47	4.70	4.63	2.73	1.93	2.53	2.70
leather	2.13	2.29	2.55	1.10	1.35	2.03	1.03	1.06	2.10	3.57	2.88	2.83	1.70	1.71	2.76
mango	1.30	1.53	1.63	1.30	1.37	2.53	2.27	1.68	3.63	3.20	3.21	2.33	2.70	3.26	3.30
melon	1.00	1.26	1.30	2.20	2.00	3.50	4.43	6.21	5.27	1.70	1.63	1.77	1.77	2.58	3.17
milk	1.30	1.58	1.57	3.20	3.32	4.00	4.57	3.26	3.47	1.87	1.16	2.20	2.60	1.84	2.80
moth ball	1.38	1.79	2.17	1.55	1.32	1.83	1.38	1.05	2.17	4.86	5.00	3.50	1.52	2.00	3.23
moldy	1.67	2.42	2.20	1.07	1.05	1.40	1.13	1.26	1.23	1.97	2.89	2.23	1.07	1.21	1.50
mushroom	1.70	2.21	3.10	1.07	1.00	1.43	1.00	1.74	1.60	1.60	3.05	2.27	1.07	1.53	1.73
musk	2.30	1.89	2.73	1.33	1.06	1.83	1.70	1.22	2.27	3.67	2.50	2.37	2.90	4.22	3.50
nutmeg	1.37	1.63	2.40	1.27	2.47	2.10	1.30	1.68	2.40	2.23	2.37	2.33	1.30	1.21	2.37
orange blossom	1.03	1.21	1.97	2.27	1.32	1.97	2.20	1.16	2.40	3.87	4.21	2.30	2.63	2.58	3.63
peanut	1.30	1.42	2.48	3.37	3.53	2.55	2.73	2.68	2.55	2.03	1.21	2.45	1.30	1.26	2.59
pine	1.40	1.16	1.77	1.10	1.21	2.10	1.43	1.21	2.40	3.73	2.84	2.70	2.43	2.32	3.93
pineapple	1.00	1.00	1.60	2.43	2.05	3.27	4.93	5.16	4.40	2.17	1.68	2.23	2.13	1.63	3.03
rose	1.03	1.26	1.60	1.53	1.53	2.53	2.43	1.84	3.70	3.90	3.63	2.10	4.00	3.53	4.07
soap	1.10	1.00	1.53	1.33	1.00	1.73	1.63	1.00	1.87	5.27	5.83	3.00	3.70	3.78	4.63
strawberry	1.10	1.00	1.17	2.90	3.16	4.03	6.20	5.37	5.67	1.73	1.47	1.77	2.27	1.95	3.53
tea	2.23	2.28	1.69	1.30	1.50	2.38	1.27	1.00	2.10	1.97	1.5	2.21	1.67	1.33	2.59
truffle	2.87	4.17	2.80	1.13	1.72	2.37	1.07	1.22	2.40	2.03	1.44	1.97	1.20	1.50	2.13
vanilla	1.03	1.00	1.33	2.83	3.74	3.80	3.97	4.32	3.13	2.37	1.53	2.37	3.93	2.68	3.63
violet	1.07	1.22	2.29	1.67	1.39	1.93	3.97	2.83	2.39	2.90	2.67	2.93	2.67	3.50	3.25
walnut	1.13	1.79	1.83	2.07	5.00	2.57	1.57	2.89	2.47	1.17	1.21	1.97	1.17	1.21	2.13
wintergreen	1.13	1.11	1.27	1.03	1.26	2.13	1.50	4.16	2.70	3.00	2.26	2.03	1.87	1.68	2.87
woody	1.33	2.53	2.47	1.07	1.63	2.27	1.67	1.42	2.13	3.03	1.89	2.13	1.63	1.42	2.30

Appendix 1 Extended

flower			fruit			medicine			musty			nature			spice		
FR	US	VN	FR	US	VN	FR	US	VN	FR	US	VN	FR	US	VN	FR	US	VN
2.93	2.42	2.60	1.63	1.58	2.67	2.20	2.32	3.47	1.70	3.05	2.20	2.50	1.58	2.73	2.80	2.21	2.60
1.93	1.63	3.10	2.13	1.63	2.93	2.73	2.63	2.60	1.57	1.47	1.50	2.60	1.26	2.20	3.20	3.16	3.43
3.10	3.42	3.70	4.00	3.95	4.07	2.83	2.21	1.80	1.43	1.05	1.43	2.80	1.53	2.67	1.13	1.89	1.97
2.23	2.68	3.27	4.50	5.00	3.77	2.00	2.16	2.07	1.77	1.37	1.43	2.57	1.68	2.20	1.13	2.00	1.57
1.23	1.26	2.83	1.30	1.11	2.73	1.57	1.79	2.20	1.67	3.21	2.30	2.10	2.26	2.13	1.70	1.84	2.03
1.37	1.32	1.90	1.07	1.05	2.13	1.80	2.05	2.50	2.13	5.11	2.73	1.93	3.26	2.17	1.83	1.58	1.77
2.07	1.58	3.03	1.57	1.37	2.73	2.00	1.79	2.43	1.83	1.32	1.33	2.60	1.53	3.77	4.97	6.05	3.47
1.60	1.42	1.47	1.03	1.26	1.57	1.37	1.63	2.20	2.03	4.37	3.77	2.43	3.89	2.07	1.43	1.26	1.33
2.03	1.79	2.17	1.23	1.26	2.37	3.10	3.11	3.23	1.90	1.84	2.37	2.77	1.68	2.23	5.00	5.68	2.17
1.87	2.22	3.20	2.03	2.39	3.40	2.73	1.61	1.63	1.20	1.61	1.20	1.73	1.44	1.97	2.10	3.28	1.67
1.70	1.95	2.43	1.33	1.37	1.90	2.23	2.58	2.20	1.23	2.32	2.20	1.67	2.53	2.20	1.20	1.95	1.53
1.47	1.42	2.23	1.03	1.05	2.43	4.90	5.47	4.93	1.87	1.68	1.50	2.70	1.53	2.50	1.47	1.47	2.00
2.10	1.79	2.67	2.07	1.95	3.23	2.07	2.95	2.10	1.63	2.32	1.67	2.97	2.74	3.03	3.37	3.68	3.17
1.17	1.56	1.67	2.20	1.44	1.83	1.50	1.56	1.97	1.63	3.61	3.03	1.87	2.50	1.67	2.70	2.56	2.07
2.87	1.94	2.23	1.70	1.39	2.23	2.03	2.50	2.20	1.63	3.00	2.03	3.20	3.06	2.23	2.23	2.39	1.73
4.70	4.58	3.57	1.40	1.74	2.67	1.80	2.84	2.23	2.37	2.16	2.73	3.43	2.53	2.87	1.73	1.79	1.60
4.83	2.84	3.10	1.37	1.21	2.93	1.73	2.68	2.77	2.33	1.68	2.33	4.23	2.53	2.70	1.83	2.21	2.17
1.37	1.06	1.90	1.10	1.12	2.00	2.40	3.29	2.45	1.73	3.41	3.10	2.03	2.41	2.31	1.93	2.06	2.52
3.97	3.26	2.77	2.90	2.74	4.20	2.27	2.58	2.07	2.30	2.37	1.80	2.87	2.58	2.40	1.73	1.79	2.20
2.43	2.84	3.33	6.23	5.79	5.40	1.30	2.11	1.93	1.47	1.16	1.20	3.37	1.63	2.83	1.13	1.53	1.77
2.13	2.47	2.73	2.90	2.26	3.00	1.93	1.89	2.30	1.43	1.84	1.73	1.97	2.47	2.53	2.17	2.68	2.80
1.48	1.21	2.60	1.34	1.21	2.00	2.34	2.89	2.70	1.69	2.84	2.77	1.86	1.95	1.73	1.55	1.32	1.57
1.77	1.84	1.63	1.33	1.11	1.53	1.67	2.05	2.17	5.80	3.53	5.97	5.17	5.26	2.23	1.73	2.05	1.43
1.50	1.26	1.83	1.17	1.16	1.73	1.23	3.58	1.83	5.53	3.32	4.53	5.23	2.74	2.10	1.77	1.63	1.60
2.97	2.17	2.53	1.40	1.28	2.57	2.03	2.39	2.17	1.67	2.22	2.10	2.30	1.67	2.07	1.97	1.50	1.67
2.03	1.68	2.60	1.37	1.16	2.37	2.47	2.89	2.37	2.77	2.47	3.57	3.17	1.63	1.97	4.83	4.42	2.20
3.27	4.11	4.30	2.07	1.53	2.83	3.47	1.89	1.97	1.23	2.32	2.27	2.53	3.00	2.50	1.50	1.53	2.00
1.80	1.63	1.90	2.07	1.53	2.24	2.03	1.68	2.34	2.23	2.58	2.93	2.63	2.37	2.17	2.70	3.11	1.79
1.80	2.42	2.63	1.23	1.21	2.30	2.70	2.47	3.27	2.73	2.89	2.47	2.93	3.42	2.20	1.77	1.84	2.33
1.87	2.68	3.47	5.87	5.84	4.50	1.90	1.74	1.90	1.23	1.47	1.90	2.90	2.05	2.67	1.23	1.84	2.17
3.87	4.21	3.37	1.83	1.53	3.03	1.77	1.79	2.03	1.30	1.53	1.63	2.90	2.21	2.27	1.13	1.16	1.73
2.67	1.72	2.43	1.23	1.06	2.33	1.83	1.94	2.43	1.23	1.28	1.57	2.17	1.67	1.87	1.30	1.17	1.73
2.13	2.68	3.30	4.93	4.95	4.63	2.40	2.21	2.00	1.17	1.05	1.30	2.63	1.79	2.37	1.20	1.89	1.87
2.53	1.39	2.93	1.13	1.00	2.17	2.10	2.33	2.00	2.57	2.78	2.38	3.03	3.06	2.45	3.03	2.00	2.17
1.53	1.06	2.17	1.13	1.17	2.10	1.50	2.28	2.23	2.83	4.44	2.60	2.87	3.11	1.73	1.73	1.44	2.03
3.27	2.58	3.03	2.37	1.89	2.93	1.80	1.47	2.27	1.30	1.47	1.50	2.63	2.05	2.17	3.37	3.53	1.80
3.83	3.17	2.79	2.13	2.00	2.64	2.07	2.17	2.07	2.27	2.06	2.50	3.07	1.89	2.14	1.33	1.44	1.82
1.10	1.53	2.17	1.93	1.79	2.03	1.43	1.84	4.03	2.70	2.47	2.10	3.50	2.05	2.07	5.57	3.32	2.27
1.37	1.95	2.47	1.03	1.47	1.97	5.70	5.16	4.83	1.47	1.37	1.40	1.53	1.37	2.10	1.50	2.32	1.83
2.33	2.05	2.43	1.10	1.26	2.20	1.93	2.37	2.43	3.13	2.68	3.37	3.37	4.37	2.43	2.33	2.05	2.07

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